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Status Report

THERMAL PROCESSES FOR LIGHT OIL RECOVERY

Project BE11A, Milestone 6, FY88

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SUMMARY

All of the tasks in this project were completed as scheduled.

Results from the gravity override investigation indicated that gravity override in light oil steamfloods can contribute substantially to poor sweep efficiencies. In addition, the oil recovery profiles appeared to depend upon the oil composition of the individual crude oil being evaluated. Results from the capillary pressure and wettability studies indicated that Berea sandstone cores become more water-wet at elevated temperatures.

Two topical reports entitled *Steamflooding Light Crude Oil Reservoirs, A State-of-the-Art Review*,[1] and *Thermal Recovery of Light Crude Oils Using Steam—A Laboratory Study Using a Two-Dimensional Physical Model*,[2] were delivered. The second report was for inclusion in a final report for the Annex IV Agreement. Four technical presentations were given discussing work performed for this project. Two of these presentations were delivered at Annex IV meetings, (SUPRI, October 22-23, 1987, and INTEVEP in Venezuela, April 6-7, 1988). The third presentation was of paper SPE 17447 which has been accepted for publication in SPE Reservoir Engineering.[3] The final presentation was about our work on capillary pressure measurements (Second Annual Technical Conference of Society of Core Analysts, Houston, August 17-18, 1988).

INTRODUCTION

Steamflooding currently is the most used method of enhanced oil recovery (EOR). Historically, it has been associated with heavy oil; however, heavy oil reserves account for only about 10% of the total domestic reserves. To exploit the EOR potential of the remaining 90%, steamflooding should be considered because of its demonstrated effectiveness in recovering oil.

During FY84, NIPER conducted research in Project OE4A to determine the effects of oil and rock properties on the efficiency of steamflooding for oil recovery from light oil reservoirs. The results of the work performed during that year were reported in the FY84 Annual Report[4] and in the topical report, *Light Oil Steamflooding: Core Flood Experiments*.[5] That project was reactivated in FY87 and continued in FY88. Additional research was conducted on the effects of temperature on capillary pressure measurements of light oils.

Research conducted in FY87 and FY88 considered the effect of light oils on the gravity override of the steamfront. The results indicated that gravity override was significant for the recovery of light crude oils. In addition, the oil recovery profiles of the crude oils used in these experiments were dependent upon the chemical composition of the crude oils. The chemical composition of the crude oil can be estimated by the relative composition of the light ends (C_5 to C_{10}). Linear steamfloods in the laboratory were found to give unrealistically high recovery efficiencies, presumably because the effects of gravity override were minimized.

The results from the capillary pressure studies conducted in FY87 and FY88 showed the effects of varying temperature on capillary pressure values for simple core/fluid systems. Synthetic oils with selected components were tested in FY87 to determine their effects on wettability and capillary pressure. Actual crude oils, including some with selected components removed, were tested in FY88 to compare actual crude oils with the simplified systems tested in FY87. In all cases, an increased temperature corresponded with an increased residual water saturation and a more water-wet core.

The overall objective of this project is to improve the understanding of the basic mechanism responsible for the improvement of light oil production using steam. In FY88, the experimental study on gravity override initiated in FY87 was to be continued and concluded, the investigation of temperature effects on capillary pressure and wettability was to be continued, and the applicability of light oil steamflooding to shallow stripper well operations was to be considered. All of these tasks were completed as scheduled giving valuable information for other investigators interested in light oil steamflooding processes. A summary of the progress for each individual task is given in the following sections.

STATUS OF PROJECT TASKS

Task 1. Complete light oil steamflooding experiments started in FY87 to determine the importance of gravity override on light oil steamflooding.

The experiments conducted in FY87 were reviewed, and additional experiments were planned for FY88 to complete the initial investigation of gravity override with light oil steamflooding. After the initial set of experiments were conducted in FY87, additional technical questions arose, and they were addressed under this task. These additional experiments included:

1. Two-dimensional steamflood experiments with two additional crude oils that had substantially different densities from those used in the previous experiments; and
2. Two-dimensional steamflood experiments of sandpacks that have been waterflooded before the injection of steam.

A very light crude oil of 48° API gravity and a heavy crude oil of 14° API were selected for the first set of experiments. Wade lease and Delaware-Childers crude oils were selected for the second set of experiments.

All of the experiments were completed as scheduled.

Gravity override was found to be a potential problem for steamflood processes of even the lightest crude oils. This phenomenon contradicted literature simulation studies that suggested gravity override would not affect the sweep efficiencies of steam in light oil reservoirs as much as in heavy oil reservoirs. The recovery efficiency appeared to be strongly influenced by the chemical nature of the individual crude oil. Those crude oils containing a higher percentage of light ends (C_5 to C_{10}) were recovered more efficiently.

Waterflooding the sandpack before the injection of steam resulted in lower total oil recoveries as compared to recoveries from previous steamflood experiments without waterflooding. Apparently, the waterflood created fluid channels that were detrimental to the subsequent steam distillation processes. Steam distillation has been established as the primary mechanism of oil recovery by steamflooding for light crude oils.

<u>Task 2. Correlate the experimental steamflooding information obtained during the period FY84 through FY87 with fundamental principles documented in the literature</u>.

The strongest method for deriving conclusions from experimental results requires a comparison of the experimental results with expected values calculated from equations that represent known or proposed theoretical principles. Task 2 was included in this project to make this comparison. The activities outlined in this task included:

1. Complete a literature search of available models of potential use for our experiments;
2. Search for existing simulators from alternate sources that may be applicable to our experiments;
3. Adapt from previously existing models and/or simulators a computer modeling tool capable of comparing our experimental steamflooding information with fundamental principles; and

4. Initiate a sensitivity study to compare our experimental data with predicted values to develop an efficient method of planning future experiments and to compare present and future experimental results from our laboratory with results from other laboratories and field tests.

Several benefits resulted from this work and that of other laboratories and field tests. These benefits include the validation of our experimental results, a more realistic comparison of our results with other laboratory results, and a potentially broader application of experiments performed in our laboratory to other situations of interest.

All of the activities were completed as scheduled, although less was done this year for activity 4 under this task than was originally anticipated. This work will continue through FY89.

A search of the literature and other sources for existing models and simulators provided most of the subroutine models and solution methods applicable to steamflooding of light crude oils. However, the lack of a complete simulator in a usable form for adequately evaluating our particular experiments with the two-dimensional apparatus necessitated the creation of a new code. Consequently, a disproportionately larger portion of the effort applied to this task in FY88 was consumed by the third activity. The equations incorporated into the computer modeling tool were presented in a previous quarterly report.[6] Sensitivity studies (activity 4) of the experimental parameters and a comparison of experimental results with predicted values were started this year and will continue through FY89. The results of that work will be reported next year when more information will be available.

Task 3. Determine the effect certain light crude oils have on capillary pressure at elevated temperatures.

To extend the experimental results obtained in FY87 to more realistic and complex systems, test procedures similar to those performed in FY87 were to be conducted on actual crude oils and crude oil blends for this task. The information obtained from these and previous experiments would then be useful for considering the effects of increased temperature by steam on the recovery processes of oil in the reservoir. New London crude oil (34.2° API) was selected for these experiments.

All experiments were completed as scheduled.

Wettability measurements of New London crude oil at 75°, 150°, and 250° F indicated that the Berea sandstone cores became more water-wet with increasing temperature. Results from capillary pressure curves determined previously indicated that the residual water saturations increased with increasing temperature, which implied that the cores were becoming more water-wet at higher temperatures. The wettability measurements determined according to task 3 with the New London crude oil provided more convincing proof of this relationship of temperature and wettability. Wettability measurements were attempted at 350° F with the New London crude oil, but the sample cell proved unreliable at this temperature.

Additional wettability experiments were conducted with modified New London crude oil. The asphaltene and polar compounds were selectively removed from the crude oil to determine how these compound groups affected the wetting process. As before, the Berea sandstone core became more water-wet with increasing temperature. However, the removal of the asphaltene or the polar compounds from the original crude oil caused the resulting crude oil to render the core more oil-wet than with the original crude oil. On the other hand, the removal of both asphaltene and polar compounds from the original crude oil resulted in wettability values that did not differ substantially from the original crude oil. Apparently, the asphaltene and polar compounds are interdependent, and the removal of one group destabilizes the other and results in changes of their adsorption properties to the rock surface. This result also has been noted in previous work performed at NIPER.

Task 4. Support the DOE in its cooperation with Venezuela by attending the Annex IV meetings.

Experimental work conducted in our laboratory was presented at the Annex IV meetings scheduled for this fiscal year. The scheduled meetings were held at SUPRI, October 22-23, 1987, and at INTEVEP in Venezuela, April 6-7, 1988. A section of the final report entitled, *Thermal Recovery of Light Crude Oils Using Steam—A Laboratory Study Using a Two-Dimensional Physical Model*,[2] which described some of the results presented, was submitted in compliance with the Annex IV agreement.

Task 5. Examine the applicability of light oil steamflooding to certain reservoirs, including shallow, stripper well operations.

As previously mentioned, steamflooding has proved to be highly successful in recovering crude oil. The purpose of this task was to investigate other potential applications of steamflooding to less traditional types of reservoirs, such as to shallow, stripper well operations. This task was separated into three activities:

1. Select typical conditions of a stripper-well type of reservoir (light crude oil);
2. Compare these conditions with published selection criteria for successful steamfloods; and

3. Use the Department of Energy's (DOE) steamflood predictive model to evaluate the conditions of the test well for potential success.

All activities were completed as scheduled.

Delaware-Childers field in Nowata County, Oklahoma, was selected for this investigation. The formation depth was 600 ft, the porosity was 20%, the absolute permeability was 60 md, and the oil saturation was 30%. Selection criteria suggested by King et al.[7] were used for the second activity. All four oil production algorithms of DOE's predictive model were used in the third activity.

A comparison of the reservoir conditions to that of the selection criteria indicated that the porosity-oil saturation product and the absolute permeability were below the minimum values for economically successful projects. Calculation of the oil production histories using the DOE steamflood predictive model[8] showed that the water-oil ratios never dropped below 10. The water-oil ratio of 10 is often used as a benchmark figure. A value greater than 10 is typical of an uneconomic situation. The shallow, stripper well conditions selected for this study do not appear to be favorable for steamflooding.

CONCLUSIONS

Conclusions from experimental work conducted this year are as follows:

1. Gravity override remains a potential problem for light oil steamflooding operations;
2. The recovery efficiency of light crude oils in steamflooding is strongly influenced by the chemical composition of the individual crude oil;
3. Waterflooding the porous matrix results in lower total oil recoveries as compared to previous steamflood experiments without waterflooding;

4. As with mineral oil, New London crude oil in the presence of Berea sandstone gives a mildly water-wet condition and becomes more water-wet as the temperature is increased; and

5. Shallow, stripper well operations do not appear to be favorable candidates for steamflooding operations.

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